LOSS OF MARTIAN ATMOSPHERE BY IMPACTS SINCE THE FORMATION OF THE MARTIAN GEOLOGIC RECORD. D. A. Brain, B. M. Jakosky. Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309

Overview

The Martian surface geologic record suggests that the atmospheric surface pressure was once warm enough for liquid water to be stable on the surface. Loss mechanisms for Mars' early atmosphere include impact erosion, which was likely a significant process during periods of heavy bombardment. Melosh and Vickery have shown that the primordial atmospheric surface pressure could have been as high as 1 bar, 4.5 billion years ago. Here, we examine the role of impacts on Martian atmospheric evolution since the beginnings of geologic history currently preserved on Mars. In this way, we can determine the specific role played by impact erosion of the atmosphere in causing changes in climate that are inferred from geomorphology.

Foundation

The model by Melosh and Vickery shows that for a given planet, impact of projectiles larger than a given mass can remove the entire atmosphere above the tangent plane to the planetary surface at the point of impact. For Mars, they show the smallest impactor to be ~$4x10^{13}$ kg, or ~3 km in diameter for a silicate object; oblique impacts may reduce the minimum mass by a factor of five. Using an expression for impactor flux during heavy bombardment, a derived relation between cumulative crater density (N(t)) and surface age is well-fit to the lunar crater record. This expression is then integrated along with the effects of sufficiently large impactors on the atmosphere to obtain an expression for the surface pressure relative to the current surface pressure ($P(t)/P_0$) as a function of time from the present. In this way they predicted that Mars' early atmospheric surface pressure was at least 100 times greater than its present value 4.53 billion years ago, or ~1 bar.

Constraining Early Surface Pressure

Expressions are given by Melosh and Vickery for both P(t) and N(t). Thus, we are able to eliminate time as a parameter from the two relations and construct a plot of N vs. P. In this way we can use the observed cratering record on Mars to constrain the integrated atmospheric loss; this approach will work better for Mars due to the lack of an absolute calibration for the cratering flux history. Using two different estimates for Martian surface crater density in the most heavily cratered (and thus oldest) areas of Mars, we can constrain the ratio P/P_0 to values of 2-10. References by Tanaka and Hartmann independently confirm the crater abundances used, which depend upon the minimum crater diameter taken. Values of 2-10 mean that the Martian atmospheric surface pressure would have been only 12-60 mbar at the time that the earliest preserved surface on Mars formed, barring sources or additional sinks of atmosphere since then. For the early surface pressure to have been as high as 1 bar at the time of formation of the oldest observed geological features, the surface crater densities in those regions would need to be significantly higher than any measured values.

Implications

This simple calculation suggests that impacts may have contributed to the loss of up to 60 mbar of atmospheric surface pressure since the onset of the Martian geologic record. This is not enough to account for the loss of an atmosphere thick enough to form these features, and additional loss mechanisms would be required.

References

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